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New laser meridional refractometry technique (RMA) as a tool to study irregular (non-toric) astigmatism and the Sine-Square law

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Abstract

A new refractive technique is reported that uses a stenopaeic slit with laser light to enable spherical lens neutralization of equally spaced meridians of the test eye. Due to the finite width of the slit, the subject can observe cross sections of a modified conoid of Sturm by laser light reflected from a stationary diffusing surface. The endpoint for a given meridian is reached when appropriate sphere power places the center of the modified conoid on the retina, resulting in perception of minimum conoid cross section size. This technique is referred to here as Running Meridional Analysis (RMA). The goal of this research was to use RMA to test the validity of general application of the "Sine Squared Law" to astigmatic eyes regardless of the amount of astigmatism. Suggestions are offered on application of RMA to contact lens over-refractions.

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NEW LASER MERIDIONAL REFRACTOMETRY TECHNIQUE (RMA) AS A TOOL TO STUDY IRREGULAR (NON-TORIC) ASTIGMATISM AND THE SINE-SQUARE LAW.

By

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I graduated from Pacific University May 1990 with the degree of Doctor of Optometry. I graduated with a Bachelor degree in Biology and Human Development from University of California Riverside in 1985. Before this I spent three years at Pasadena City College studying Natural Sciences, while at the same time attending the Liberal Institute of Science and Technology also in Pasadena. I'm a recipient of the Health Professions Scholarship Program of the United States Army. After graduating I will be stationed at the 97th Division hospital in Frankfurt Germany. I will spend three years practicing in Germany and during this time I will work on my Masters Degree in Early Childhood Development and Education. When I complete my three years in the Army I plan to go into private pratice and specialize in the area of Learning Disabilities and Vision Threrapy associated with Education.

KEYWORDS

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ABSTRACT

A new refractive technique is reported that uses a stenopaeic slit with laser light to enable spherical lens neutralization of equally spaced meridians of the test eye. Due to the finite width of the slit, the subject can observe cross sections of a modified conoid of Sturm by laser light reflected from a stationary diffusing surface. The endpoint for a given meridian is reached when appropriate sphere power places the center of the modified conoid on the retina, resulting in perception of minimum conoid cross section size. This technique is referred to here as Running Meridional Analysis (RMA).

The goal of this research was to use RMA to test the validity of general application of the "Sine Squared Law" to astigmatic eyes regardless of the amount of astigmatism. Suggestions are offered on application of RMA to contact lens over-refractions.

INTRODUCTION

HISTORY

Laser refraction was first introduced in 1962, when Rigden and Gordon(1) and independently Oliver(2) described the speckle pattern which results when the coherent light from a gas laser is reflected from a matte surface(3). The laser light becomes scattered and produces real images of randomly changing interference patterns in front of the scattering surface and similar virtual images behind the surface. When coherent laser light is reflected from many different spots on a granular (diffusing) surface, the reflected wavefronts enter the eye and interfere optically (constructively and destructively) in the plane of the retinal photoreceptors. This generates the light and dark spots seen as "speckles"(4). This is unlike the retinoscope reflex that is thought to originate from the internal limiting membrane (the boundary between the retina and the vitreous) of the retina anterior to the photoreceptors of the retina, because retinoscopic findings usually indicate more hyperopia than subjective findings(5). The particular pattern seen is determined by the point in space that is conjugate to the observer's retina. Moreover, when the observer moves his/her head laterally, the pattern appears to move in the same direction as his/her head if the retinal conjugate lies behind the scattering surface, (hyperopia), and opposite to his/her head movement if the conjugate is in front of the surface (myopia). If the speckles do not move, just seem to "boil" the observed surface is said to be optically conjugate to the retina (emmetropia). Lenses placed before the observer's eye can eliminate this apparent movement of the laser pattern and can thereby neutralize any ametropia of the eye with respect to the scattering surface(6).

The explanation of this effect has been given(2). Briefly, it is based on the fact that a near sighted observer involuntarily focuses in front of the scattering surface, while a far-sighted observer focuses behind the scattering surface. There is a parallax effect between the impression of motion in different directions for the two cases(7). Optical and mathematical considerations in apparent movement relative to the degree of ametropia are complex and are not necessary to this report of a new modified laser refraction technique (RMA). The interested reader can refer to the literature (8,9,10,11).

In 1966 Knoll(6) reported a clinical adaptation of the laser speckle phenomenon. Realizing that head movement was difficult to control, he produced essentially the same effect for a fixed observer by moving the surface. Lenses were placed before the test eye to neutralize the apparent motion of the speckle pattern. Knoll used the instrument to study night myopia. He found 0.125 to 0.75 D of myopia in six subjects. Knoll's basic arrangement, with variations and adaptations, has been employed in almost all laser refractive studies(12).

NIGHT MYOPIA/DARK FOCUS

One important feature of speckle movement is that, since the speckles are generated by the interfering wave front at the plane of the photoreceptors, they are always in focus; that is the presence of refractive error will not influence their clarity. Changes in accommodative power are not evoked to improve sharpness, so in theory the speckle pattern should not stimulate accommodation(4). Hennessy and Leibowitz(13) demonstrated empirically that the speckle stimulus does not influence accommodation, and confirmed the theoretical prediction. Laser optometers have figured prominently in most of the recent research on night myopia and related phenomena i.e.. "dark focus". Many reports have been given on the measurement of night myopia. To mention just one, Leibowitz and Owens reported, 0.37- 2.89 D with 59 subjects. Then again, with 124 subjects, these same authors found a range from 0.0 to 4.0 D myopia (mean 1.71D., s.d.= 0.72)(4).

BICHROMATIC LASER REFRACTION

Laser refractive techniques involving the simultaneous viewing of Red (633nm) and green (514nm) speckle patterns have also been investigated. Morrel and Charman(14) showed the bichrome technique to be feasible, but most subjects found the conventional laser method, involving red speckles alone, easier to interpret. Mohon and Rodemann(15) give measurements at various wavelengths across the visible spectrum and show that the laser speckle pattern can be used as a research tool across the visible spectrum for investigating the properties of the eye at various wavelengths.

That the human eye exhibits chromatic aberration has been known since Newton's time. Chromatic aberration results in the shorter wavelengths having a shorter focus. The eye effectively becomes more myopic when the wave length of illumination becomes shorter. If one assumes the normal clinical correction was designed to bring yellow (580) into focus on the retina, on the basis of typical figures on ocular chromatic aberration one would expect the red laser speckle to be about 0.22 D more hypermetropic, and the green speckle to be about 0.40 D more myopic(14).

Wald and Griffin(16) reporting on axial chromatic aberration of the human eye, state that the refractive power of the eye increases about 3.2 diopters between 750nm and 365nm. For this reason the Purkinje shift of maximum visual sensitivity from 555nm in bright light to 510nm in dim light produces a relative myopia in dim light of 0.35 to 0.40 diopters. Futhermore one may expect the eye to become .35 to .40 diopters more myopic in going from cone to rod vision on the basis of the chromatic aberration of the eye alone. Wald also says that observations that are wholly restricted to the fovea do not display the Purkinje phenomenon.

Previous studies(14)(15) have shown that in laser refraction chromatic aberration does have an effect; the red laser as compared to the green laser shows less myopia. Long(12) inferred that, based on chromatic aberration of the eye the laser (red) would show more hyperopia than standard refraction. This is in contradiction to what Ingelstam(11) has reported " ..there is a tendency for the measured corrections to be approximately 0.25 D too negative. This effect is mainly due to the chromatic aberration of the eye. Since the laser light is red, with a wavelength of 632 A , a correction has to be made in order to obtain results for the daylight visibility curve. This wavelength implies a correction of +.32 D. according to Le Grand and +.38 D according to Ivanoff, which agrees well with the observed value if consideration is given to the finite distance of the drum."

I agree that laser refraction does show a little more minus and this can vary with different observers, but it is not due to chromatic aberration since this would give more positive results. This is based on the fact that red (633nm) wave lengths comes into focus on the retina before lower wavelengths (blue) in an over-plussed eye. The apparent over minusing effect of the laser I believe is due to its being done in a dark room, thereby allowing night myopia to appear. Futhermore the Purkinje effect does not seem to be involved since it is logical to believe the cones at the fovea are being stimulated by the laser light.

If the Purkinje shift from 555nm to 510nm is taking place than one may infer that a correction for the daylight visibility curve is in order. The eye acts more myopic with this shift, but since laser light is monochromatic a correction for this shift is not needed.

SPHERICAL/ASTIGMATIC ERROR

Knoll's pioneering work showed an encouraging correlation between the results obtained with his laser optometer and those of conventional subjective techniques for spherical errors. It was Haine, Long and Reading who reported on a laser refraction method that could be used for cylindrical error(12). Their first study(17) used 12 eyes and a 3 meridian approach with maximum cylinder correction of -1.00 D. The meridional data was transposed into sphero-cylindrical form utilizing Laurance's formula (sine-squared law.) which was rewritten as;

$$F_{x\sigma} = F_s + F_c \cos (\sigma - \Phi)$$

Where: Fs and Fc are the sphere and cylinder powers in diopters, respectively, Φ is the cylinder axis and $F_{x\sigma}$ the power in the meridian with axis oriented at angle σ.

Haine et al combined laser refractometry and "meridional refractometry" in their preliminary report. (The term "meridional refractometry" was proposed by Brubaker, Reinecke, and Copeland(18) for a technique in which three preselected meridians are neutralized using a stenopaeic slit and spherical lenses and the corrective spherocylinder lens is calculated using equations derived from Laurance's formula. The neutralization of meridians in this technique is done without the use of a laser optometer.) Haine et al's results were not satisfactory and it was concluded that it may be necessary to utilize more than three meridians to obtain the desired accuracy for cylindrical correction(17). This was done in another study using four meridians for one eye and six meridians for the other eye for each of 30 subjects(12). Long proposed handling the problem of the calculations involved by utilizing a FORTRAN program which broke down the subjective data into meridional components that correspond to the meridians studied by laser refraction. This would mean the clinician would need access to a computer in order to receive immediate feedback of test results. Once again Haine et al used a transposed form of Laurance's formula in his computer program to compare results. Results are given with correlation coefficients. For spherical power, both four and six meridian data resulted in correlation coefficients of 0.99 with subjective findings. For cylinder power and axis, four meridian data resulted in correlation coefficients of 0.89 and 0.97 respectively. All correlation coefficients were significant at the 0.00001 confidence level(12). Phillips, Sterling and Dwyer(19) also employed the laser refraction technique to calculate spherical error and cylindrical axis and power. They also found that the laser method of refraction is clinically suited for assessing spherical error, but even small inaccuracies in measuring any of the three meridians used to determine the cylindrical component, will cause the calculation of cylinder power and axis to be in error because of the nature of the math involved.

The mathematical bases for their calculations were taken from a thesis by York(20) which shows that if three meridians, A, B, and C, are measured with A being any meridian, B equalling A plus 45 degrees and C equalling A plus 90 degrees, then:

$$D\ cyl = (2B - A - C) + (C - A)$$

$$\sin 2\sigma = \frac{2B - A - C}{2}$$

$$D\ sph = \frac{A + C - D\ cyl}{2}$$

where σ = degrees of the axis away from meridian A. From these calculations spherical error and cylindrical axis and power were determined and then compared with the values for spherical error and cylindrical axis and power as determined by standard clinical procedures(19).

The reader should note that both the York and Brubaker et al equations come from Laurance's formula, ie, the sine squared law for meridional power of a cylinder lens.

$$P\sigma = S + \sin(\Phi - \sigma)$$

where Pσ is the power in the meridian at Φ, and S and C are the sphere and cylinder axis(21).

The sine squared law is based on the studies of cylindrical and toric surfaces by the Swiss mathematician and physicist, Leonard Euler(22), and it is well known that this formula is only an approximation(24). It has been accepted, however, because it does calculate the position of the best image forming blur circle of meridians in question due to a spherocylindrical lens used with a slit aperture(18). This value is traditionally given in dioptric units. It has been argued(22) that dioptric power does not exist in an off axis meridian and the sine-squared equation gives only the curvature of a toric surface. Others state that there is dioptric power in off off-axis meridians(23). I agree that the sine-squared law can give a good estimate of dioptric power when the lens in question also approximately follows the sine squared law i.e. when the lens is machined or computer manufactured.

Goldstein(22) offers a good explanation of why he concludes there is no such thing as power in any off axis meridians of a spherocylindrical lens, only in the principal meridians (and meridians parallel to one of the principal meridians). His argument is based on the definition of the diopter which depends on a focal length. He states if there is no focus then there is no diopter. In the circle of least confusion of Sturm's conoid absolutely no rays converge to create a focus and one cannot give a dioptric value to a blur circle formed by unfocused light. Goldstein does make it clear that although there is no dioptric power in the off-axis meridians there is a curvature and the sine-squared law can approximate this curvature.

The validity of the sine-squared law comes under scrutiny when it is used on a refracting surface that does not follow closely the geometry of the sine squared law. Other authors deal with this issue; Sergienko and Allev (21) report that refractive error of astigmatic eyes at off-axis positions did not agree with the sine squared law. They found that complete neutralization of the refractive error occurred in only some meridians. It was reported that each eye has a unique refractive pattern of off axis meridians that does not follow the sine-squared law. They offer a residual refractive error formula to calculate the amount of residual astigmatism:

$$K = \frac{E\ (\ Dm\ )}{n}$$

where K is the coefficient of the residual refractive error, E is the sum, (Dm) is the absolute amount of refraction at one point of measurement, and n is the number of measurements.

A modified Conoid of Sturm is offered by Sergienko et al It is a deviation from the well known conoid of Sturm that represents the astigmatic bundle.(See figures 3&4) In this modified conoid of Sturm the circle of least confusion can now be represented by the asymmetrical figure of confusion (irregular image) as can the shape of the focal bands on either side of the figure of confusion. The breadth and height of the image depends on the extent of the uncorrected refractive error in off-axis meridians. (21).

Matrix methods have been widely applied in optical calculations and are based on the sine-squared formula according to properties of regular astigmatism (24,25). Keating(23) reports that there is dioptric power in an off-axis meridian of a spherocylindrical lens. This dioptric power, however, has two components a curvature component given by the sine squared equation, and a torsional component. He states that all the standard sources are negligent in that they do not even mention the torsional component.

Later in Keating's paper he states that when isolating an off axis meridian with a stenopaeic slit the torsional component of the eye's astigmatism causes a twisting sheet of light inside the eye. In this case, no point image is formed. The best "image" (least blur) is obtained by placing on the retina the part of the twisting sheet with the shortest cross-sectional length. This shortest cross-sectional length is proportional to the dioptric power of the torsional component, but one cannot get at that image to measure its length. RMA (described in this report) does get this image. Keating offers the theory that one could use a stenopaeic slit and mathematical analysis to get this measurement. One would use the stenopaeic slit in the meridians 45 degrees on either side of the meridian in question, determine the best spherical lens for those meridians, and then use the given equations to determine the torsional components, which are also based on the sine squared formula.

Running Meridional Analysis (RMA)

The present study offers an alternate solution to deriving Keating's torsional component while simultaneously addressing the question of whether the sine squared law is valid for living astigmatic eyes. The issue of whether power exists in off-axis meridians is bypassed. Goldstein is correct, in a formal sense, but the present study treats power similarly to that of Harris(26), who suggests a more integral view of dioptric power as that associated with the whole component of the lens instead of power along meridians.

RMA permits the Doctor to determine the spherical lens power that best corrects the particular meridian in question, or the "torsional component" labeled here "the relative astigmatic power." This is achieved without having to access a computer program or plug values into equations derived from the sine squared law; the subjective results obtained are immediate. The RMA technique eliminates the ambiguous end point used in other laser astigmatic studies.

This was one of the reasons I devised a new endpoint for laser meridional refractometry, while at the same time developing a technique to independently neutralize selected isolated meridians. The subjective endpoint is reached when the circle of least confusion (or shortest cross-sectional length) of Sturm's coniod is placed on the retina. This is achieved optically by using a stenopaeic slit with laser light to enable spherical lens neutralization of any meridian in question. Due to the finite width of the slit, the subject can observe cross sections of a modified conoid of Sturm by laser light reflected from a stationary diffusing surface. The endpoint is reached when the appropriate sphere power places the center of the modified conoid on the retina, resulting in perception of minimum conoid cross section size. This corresponds to the "relative astigmatism" or "relative torsional component", and is unlike previous studies in that the subject makes a single judgement of image shape rather than judgements on direction of movement, orientation and speed of laser speckle. Futhermore, the endpoint criterion is the same for all meridians studied and does not change when studying off-axis meridians. Consequently, it does not cause confusion with high or irregular astigmats.

METHODS

The subject population consisted of 20 individuals (34 eyes, 272 meridians), ranging in age from 18-50 years. 9 females and 11 males. The majority of subjects were optometry students. Subject selection was based on their 7a and delta K's. Controls had spherical 7a's and K's less than or equal to .25 D of astigmatism. The astigmats had greater than or equal to 1.50 D. of astigmatism either corneal or lenticular. The controls were used to standardize the RMA technique in order to apply it to a validation of the sine squared law for high astimats. The apparatus was modeled after Knoll's laser optometer(6) except that the drum was not rotated. Modifications were made to one of Knoll's original gimbal mounted drums, which was used for its reflective properties. A stenopaeic slit B (Figure 1) was placed over the drum's circular aperture. The slit subtended 1 degree in length (4 inches) and .25 degrees in width (1 inch) at the subject's entrance pupil. Slit B was constructed of opaque plexi-glass and was designed to rotate from zero to 180 degrees. A another stenopaeic slit A was attached to a phoropter in the same place that the auxiliary cylinder lenses are placed, thus enabling this slit also to be rotated from zero to 180 degrees. The latter slit subtended 18 degrees length (20mm) and 1.8 degrees in width (2mm) at the entrance pupil and was constructed with opaque photographic tape (See figure 1).

A 633nm 4mW HeNe laser with a 10 D dispersing lens set in front of the laser was placed approximately 15 feet from the gimbal mounted drum with slit B. The Snellen projector was placed to project the 20/30 line at 6m(+) for the non-tested eye to view. The test eye had slit A in place, while accommodation was kept relaxed by placing a green filter over the non-tested eye so this eye only viewed the Snellen chart. Slits A and B were synchronized as they were rotated from zero to 180 degrees in 22.5 degree steps. The subject's corrective lenses were dialed into the phoropter only for the non-tested eye in order for the subject to view the 20/30 line clearly. The subject was seated 6m from slit B in a B&L chair with adjustable headrest. The headrest was set so the subject's head would always return to the same position when being tested. The experiment was conducted in a dark room. Both slits were set at 180 degrees and plus lenses were added until the subject reported that the laser light was spread out in a line. The spread out speckle line always correlated with the meridian setting of the two stenopaeic slits. (See figure 2) Plus lenses were continually removed in .25 D. steps until the image shrank to a "ball" or shortest cross sectional length before it started to spread out again. A bracketing method was used to put the best (most compact) image on the retina.(See figure 2). The distance between the over-plussed and over-minused, points which includes the circle of least confusion, is the Interval of Sturm or focal interval equivalent of the astigmia.

The dioptric power that resulted in the best blur circle was recorded for each meridian tested.

The eight meridians studied were 0, 22.5, 45.0, 67.5. 90.0, 112.5, 135.0, 157.5 degrees. (180 degrees was also recorded because zero degrees was used first as a demonstration to the subject. The same procedure was used for both controls and astigmats.

The 7a for each patient was arrived at by the standarized O.E.P. 21 point exam used at Pacific University. Each exam was done independently by a different Doctor or intern under the supervision of a advisor. The laser refraction was done only by myself.

The sine-squared formula was programmed into a spreadsheet computer program and the 7a for each astigmat was entered at the same eight meridians tested with RMA. The two values, subjective RMA values and the calculated values from the sine-squared formula, were compared.

The controls were treated the same way but obviously the calculated sine-squared values at the eight meridians studied for the spherical controls were the same as their 7a.

The data was analyzed both individually (graphically) and combined, i.e., by calculating correlation coefficients, and generating scatter plots.

RESULTS

The combined data for the astigmatic eyes is displayed in a scatterplot of the laser-determined meridional powers (RMA) versus calculated meridional powers calculated from the sine-squared law on the 144 astigmatic meridians studied. (See appendix). Correlation statistics were performed on the entire 144 meridians, which yielded an r value of .914. An individual analysis for astigmats was done by graphing each eye independently, meridian by meridian, and can be found in the appendix.

The combined data for the controls is also displayed in a scatterplot with the same parameters as the astigmats.(See appendix). Correlation statistics were also performed on the entire 128 meridians, which yielded an r value of .987.

53% of the astigmatic meridians had a greater than .50 diopter difference between RMA and that of the calculated value from the 7a and sine squared law, whereas only 5.5% of the control group's meridians had a difference greater than .50 diopter.

.50 diopters was used as a criterion since most clinical refractive procedures tend to leave the eye somewhat myopic, ocular depth of focus being relied upon to give clear vision of distant objects. Moreover, the experiment was done in the dark, ie. "night myopia" was a possible added factor(14). The laser optometer is also reported to over-correct in minus compared to standard refractive techniques by approximtely .32 D(11).

DISCUSSION

The present work shows RMA to be a valid technique for assessing the refractive error of the human eye. I was able to use RMA to find the spherical lens that put the best blur circle on the retina at chosen meridians regardless of the amount of astigmatism present. This enabled derivation of what I call the relative astigmatism, or Keating's torsional component.

I have also concluded that the sine-squared law is valid if one looks at the overall data. A correlation of .913 was found for the astigmatic eyes. The correlation for controls was .987 which showed the RMA technique is within acceptable limits in being able to determine refractive error.

Further scrutiny of the sine-squared law for each individual eye showed the sine-squared law to break down. By inspection of the two curves generated for each eye, RMA (diopters subjective) versus calculated sine-squared value (diopters calculated), one can see that although the basic shapes of the curves are the same, there are both under-and over-corrected meridians in all subjects. (see appendix). This shows that not all human eyes follow the sine-squared law and that individual eyes display unique optical characteristics. Graphs of the controls were not given since only 5.5% of the meridians studied in the controls showed greater than .50 D difference, whereas in the astigmatic subjects 53% of the meridians studied had a difference greater than .50 D.

This result did not show up in the scattergraph or correlation coefficient. But then does a Doctor base his prescription on statistical data? No, each patient in the examining chair is an individual with a unique set of refractive properties. If a Doctor has a question about one of those properties, for example, a patient's visual acuity may not be correctable to 20/20 and the patient is an astigmat, it is possible the eye does not follow the same geometry of the manufactured lens being used in an attempt to neutralize the astigmatism. RMA could be used to confirm this.

It was found that the high astigmats, 2.75 D or more, would get a fine circle like endpoint at some meridians and a larger blobbish endpoint at others. This difference and the resolution attainable at the different meridians tells the Doctor about the refractive (focusing) abilities of that meridian as related to the others. This difference of resolution did not happen in the spherical controls who obtained a fine circle like endpoint at every meridian.

If one wants to study meridians of an eye then RMA is useful. For example, in a contact lens over refraction, either for an astigmatic or spherical correction, one would use RMA to determine if all meridians were equally neutralized.

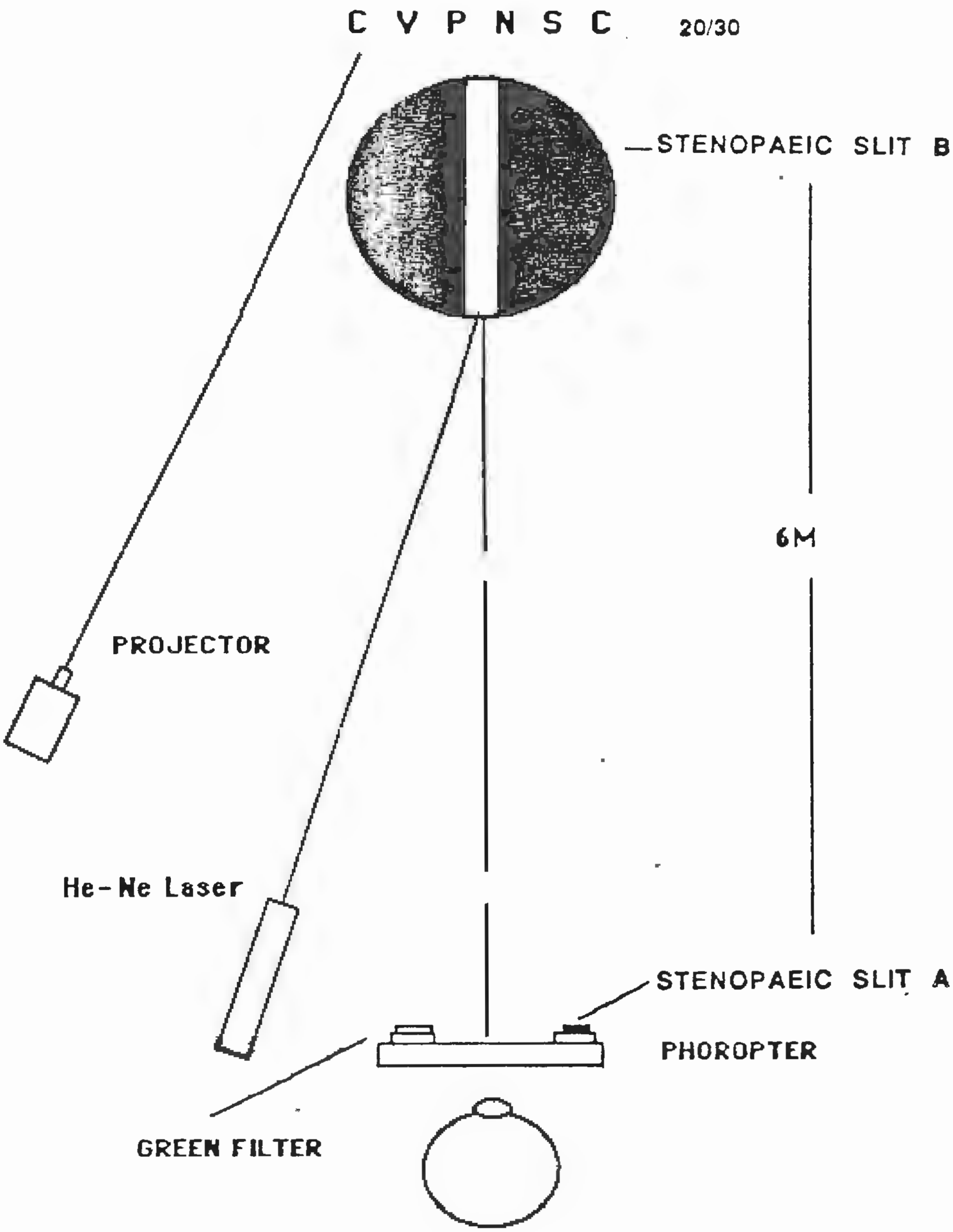
RMA would define for the Doctor the over-minused or over plussed meridians indicating where to add or subtract power. (This study is in progress)

One cannot necessarily write a cylindrical prescription directly from RMA but it can be used as an adjunct. One could take the most plus meridian for the sphere and axis and the most minus power for the cylinder. The problem one would have is that not all eyes have these two entities; most plus least minus 90 degrees apart and some show the same power for several sequential meridians. Then when they do change its not according to the sine-squared law followed by spherocylindrical lenses. RMA works fine for a spherical prescription but when it comes to astigmatism it is not straightfoward. This makes one wonder why we obtain such good results with our standard prescriptions, since the trial lenses in phoropters follow the sine-squared law and prescriptions are written from them easily enough. A likely explanation is that our visual system has built in compensation for poor image quality.

It is conceivable that in the future lenses will be ground to specific meridional changes; both the power and rate of power change will be specified for the spherocylindrical prescription in order to more exactly follow individual optical characteristics.

It has been argued that dioptric power is conceived as being a property of the lens. Therefore the definition of dioptric power should be in terms of what happens to the light at the lens not in terms of what happens to the light downstream from the lens!(23). This is formally true, but for subjective testing and determining what lens gives a patient the clearest focus it is important what happens downstream of the lens, namely at the retina and finally in the visual cortex. RMA provides information on the focusing properties of the meridian in question, and gives the best lens in diopters for the best focus at that meridian at the level of the visual cortex.

This study shows that RMA is a satisfactory technique for determining refractive status of adult human eyes. The stenopaeic slit is useful in special cases, particularly if the astigmatism is of high degree, and ordinary tests fail.



6M

FIG. 1 SCHEMATIC DIAGRAM OF APPARATUS

FIG. 2 What an observer sees through stenopaeic slit A while receiving laser light reflected through stenopaeic slit B (at the drum). Overplussing and overminusing produce the patterns shown, and somewhere between the extreme powers is the one that produces the best (most compact) blur circle. Slits A and B are synchronized as they are rotated from zero to 180 degrees in 22.5 degree steps. The dioptric power that results in the best blur circle is recorded for each meridian tested.

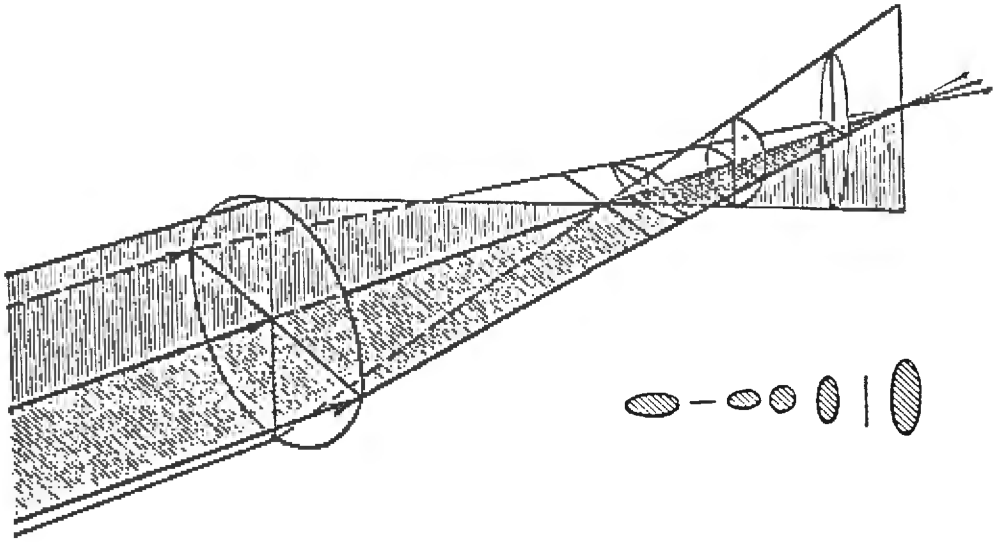


Figure 3. Sturm's Conoid.
(From Duane's Clinical Ophthalmology, Vol. 1 chap. 33, pg. 44. And, Intro to Classical and Modern Optics, Jurgen R. Meyer-Arendt, M.D. pg. 48. 1972.

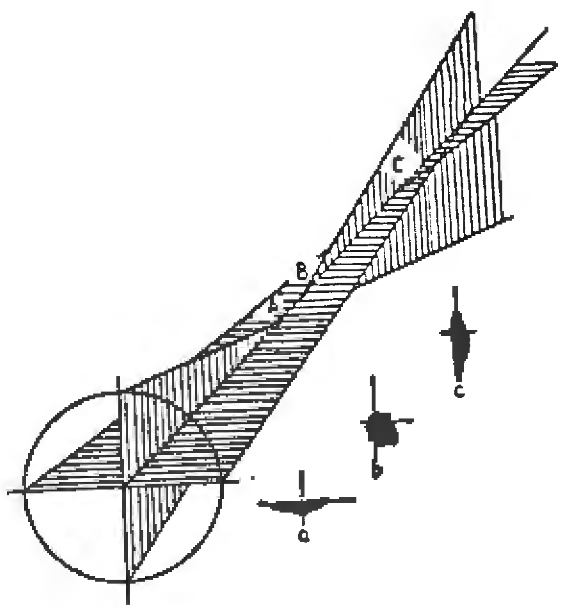
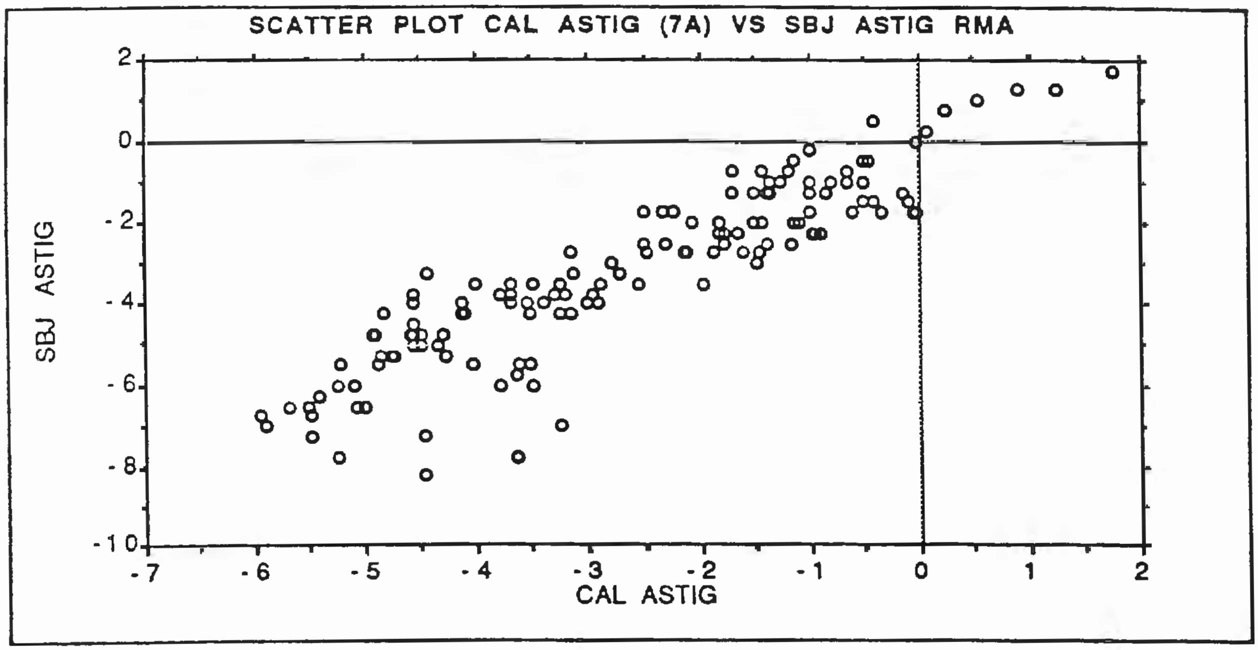


Figure 4. Modified Sturm's Conoid.
(From Sergienko and Aliev. Vis. Sci. Vol. 66 No. 3, pp. 167-169. 1989.)

SCATTER PLOT GRAPH OF CAL ASTIG (7A) VS SBJ ASTIG (RMA)



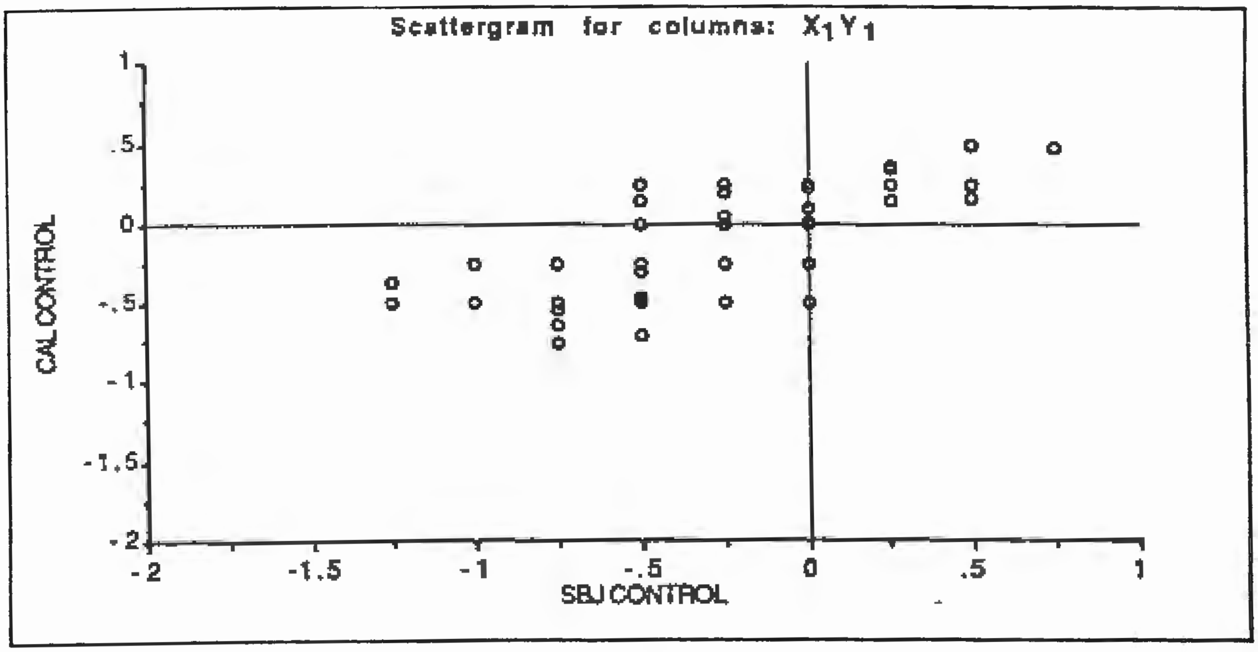
appendix

ASTIGMATIC CALCULATED (7A) VS SUBJECTIVE RMA

Corr. Coeff. X_1: CAL ASTIG Y_1: SBJ ASTIG

Count:	Covariance:	Correlation:	R-squared:
144	3.589	.913	.834

SCATTER PLOT GRAPH OF CAL CONTROLS (7A) VS SBJ RMA (RMA)

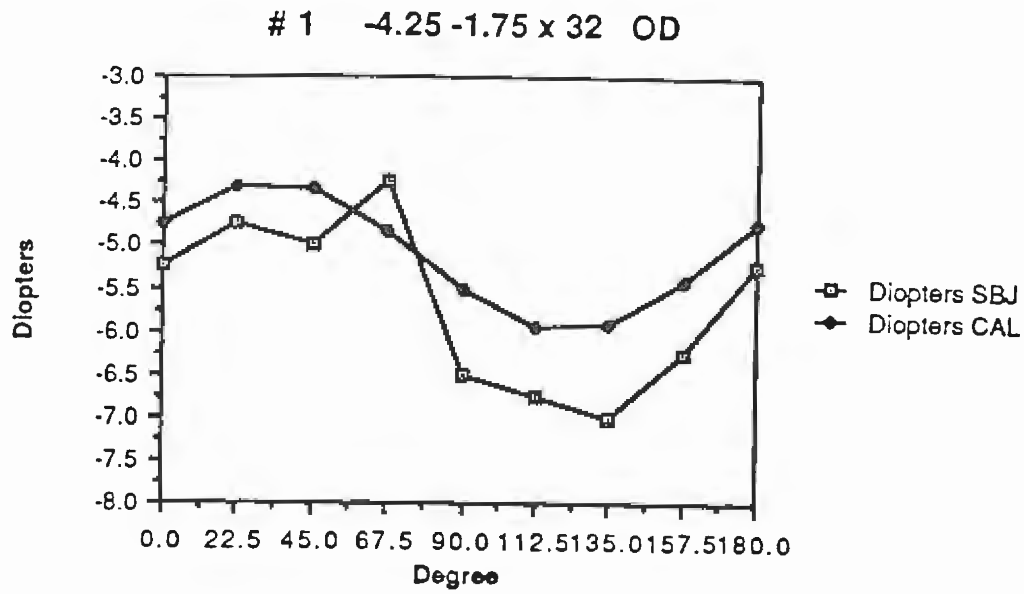


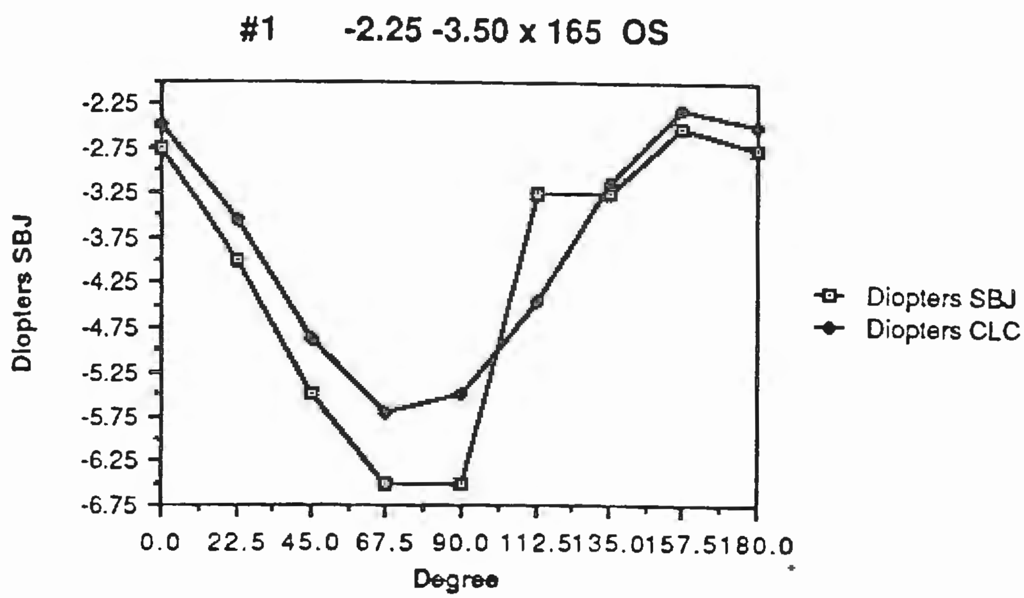
CONTROL CALCULATED (7A) VS SUBJECTIVE RMA

Corr. Coeff. X_1: CAL CONTROL Y_1: SBJ CONTROL

Count:	Covariance:	Correlation:	R-squared:
128	3.142	.987	.973

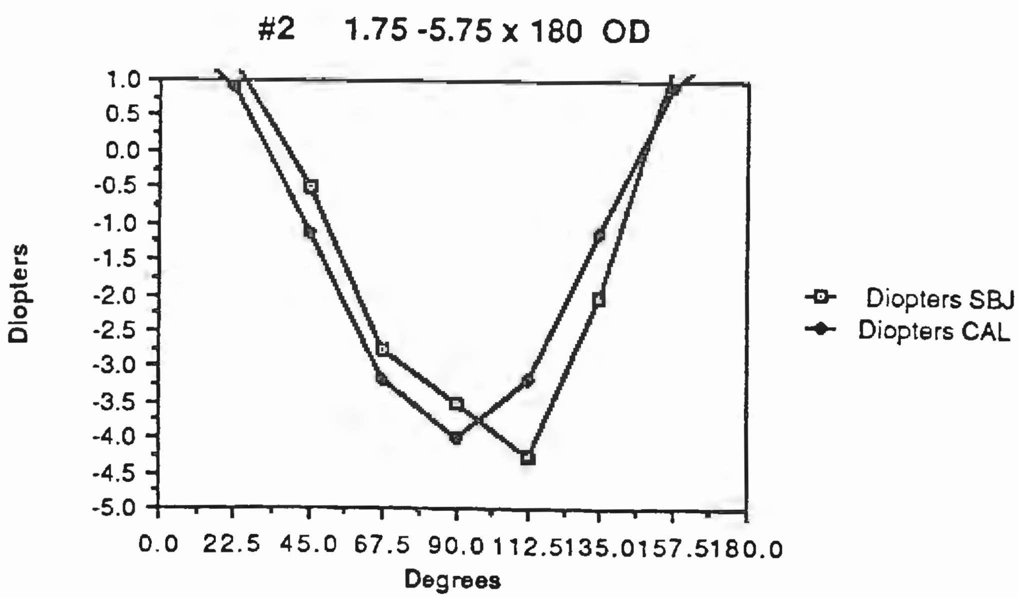
Note: 16 cases deleted with missing values.

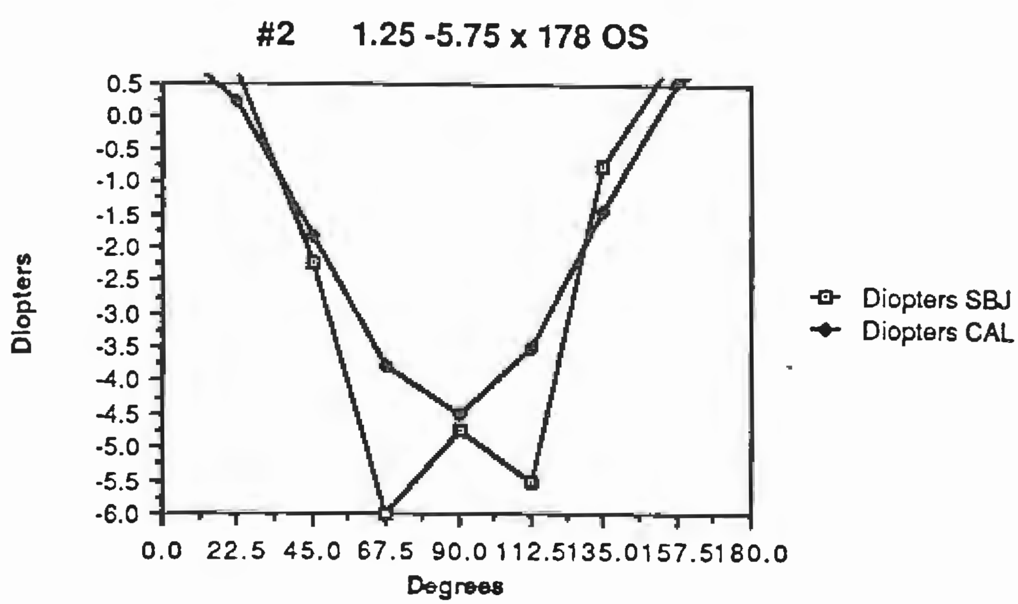




INDIVIDUAL GRAPHICAL ANALYSIS

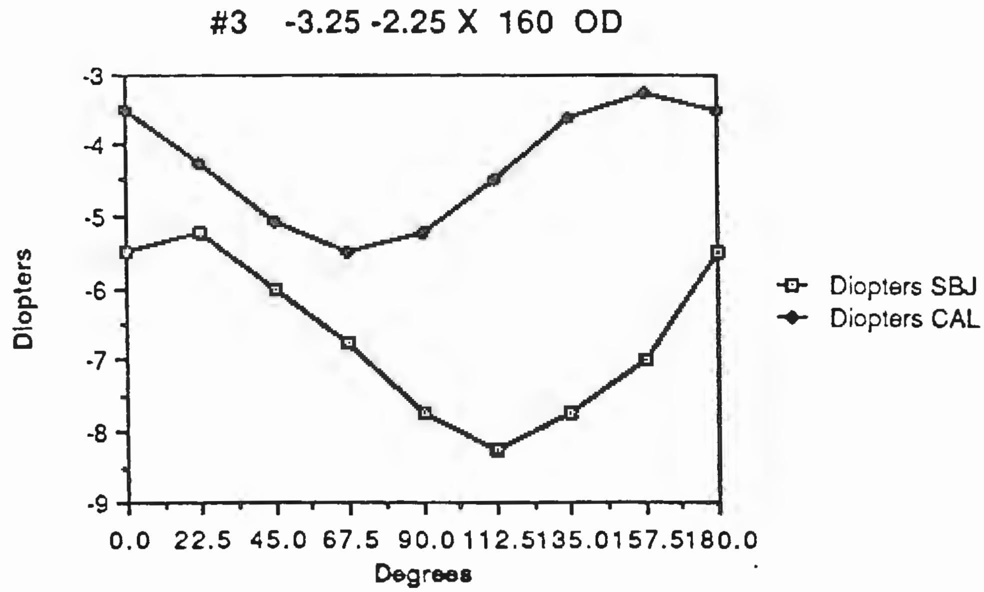
appendix

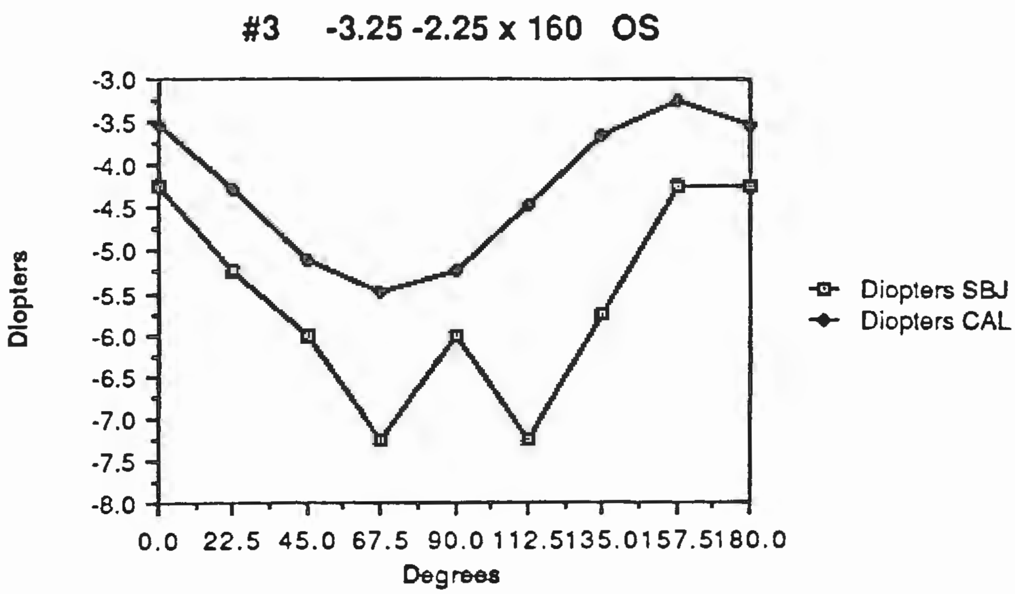




INDIVIDUAL GRAPHICAL ANALYSIS

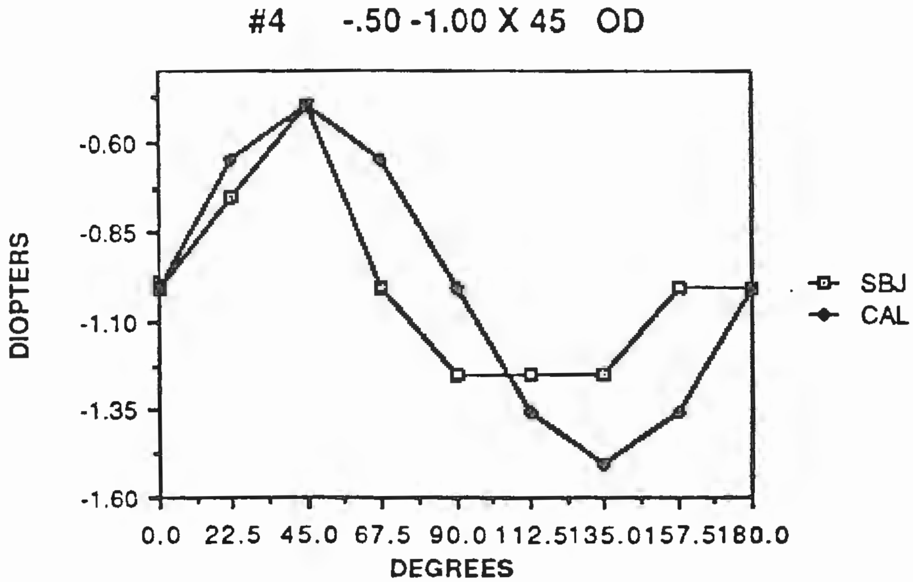
appendix

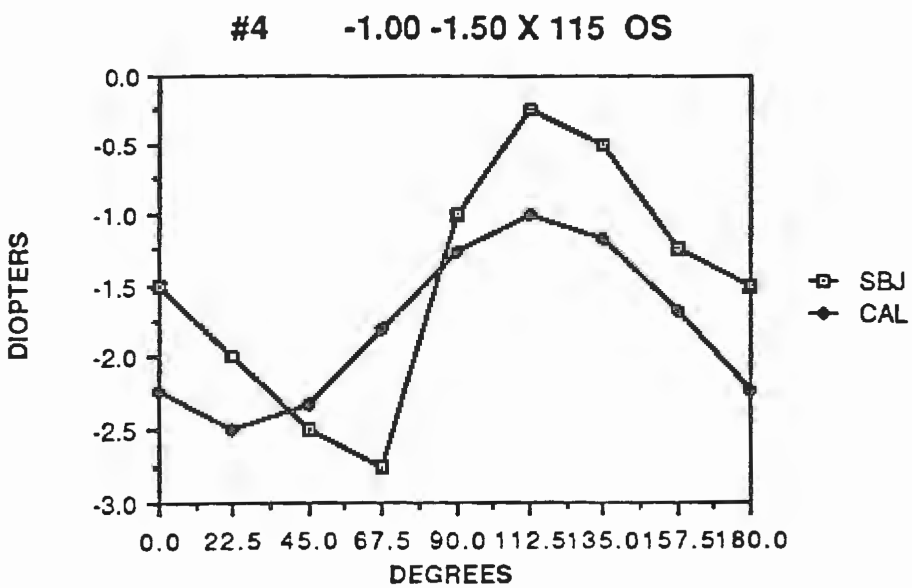




INDIVIDUAL GRAPHICAL ANALYSIS

appendix

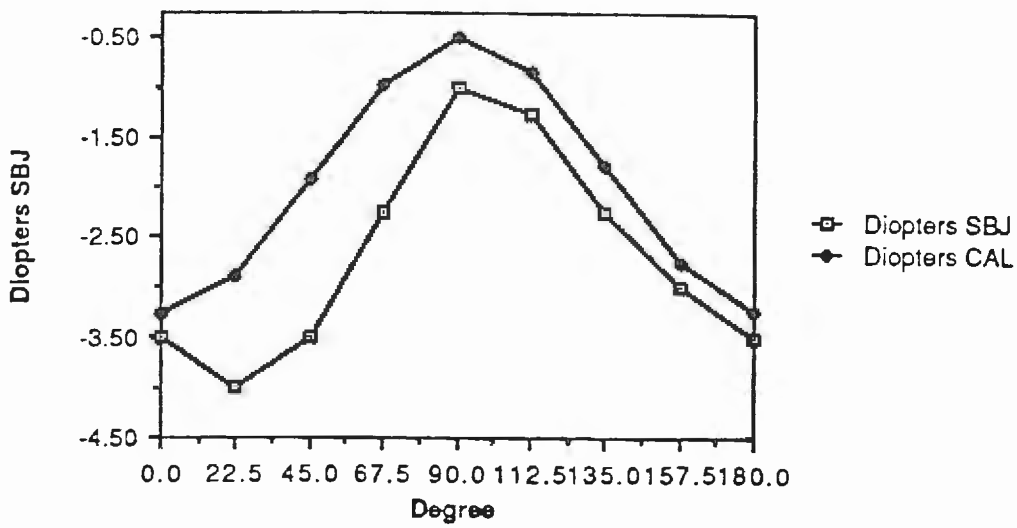




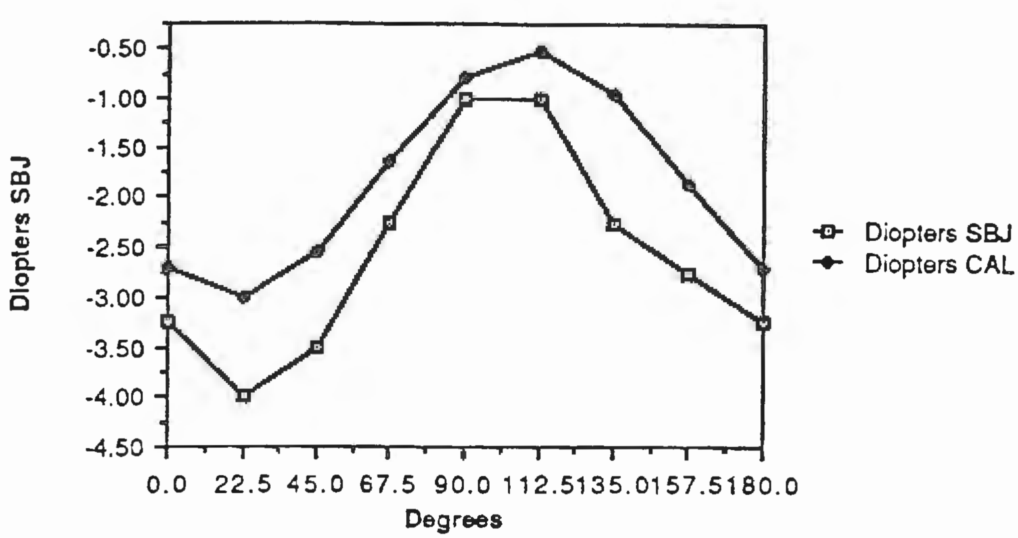
INDIVIDUAL GRAPHICAL ANALYSIS

appendix

#5 -.50 -2.75 x 92 OD



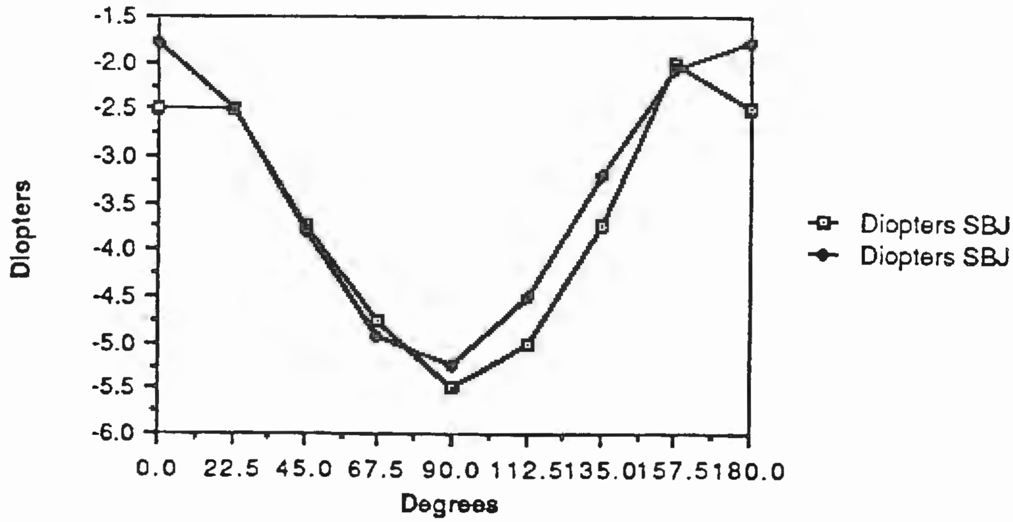
#5 -.50 -2.50 x 110 OS



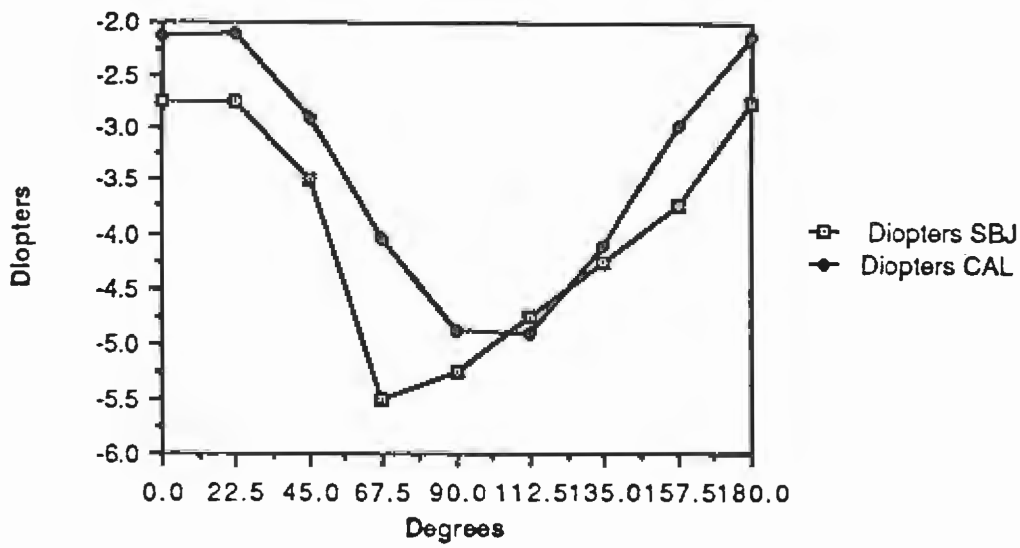
INDIVIDUAL GRAPHICAL ANALYSIS

appendix

#6 -1.75 -3.50 x 175 OD

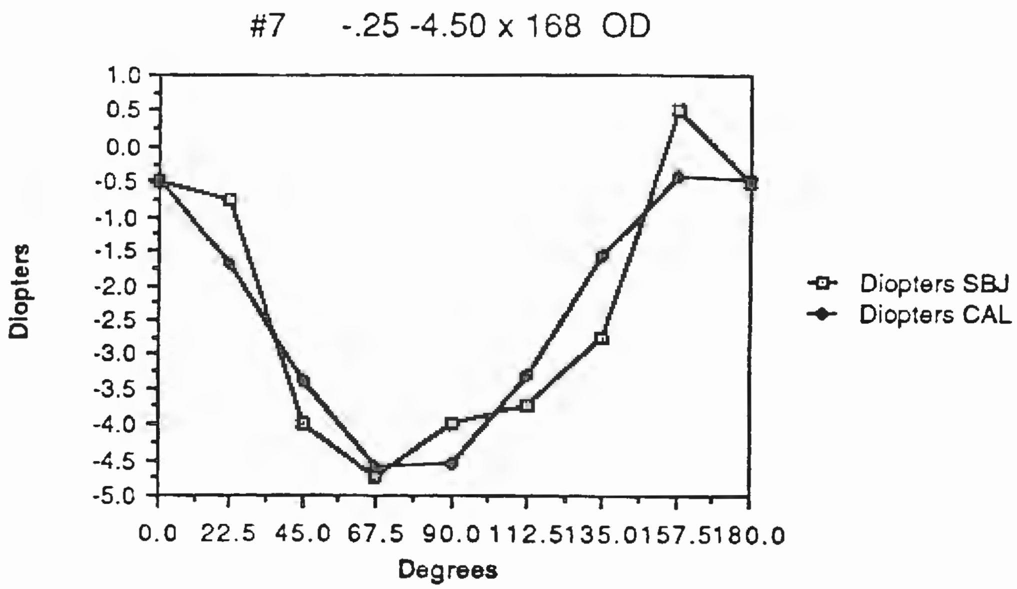


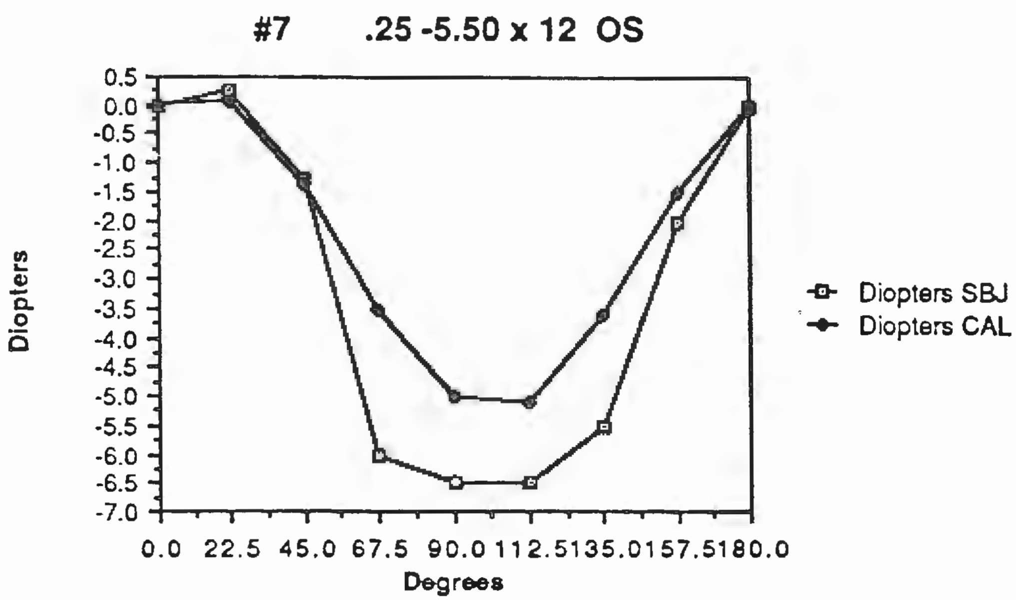
#6 -2.00 -3.00 x 12 OS



INDIVIDUAL GRAPHICAL ANALYSIS

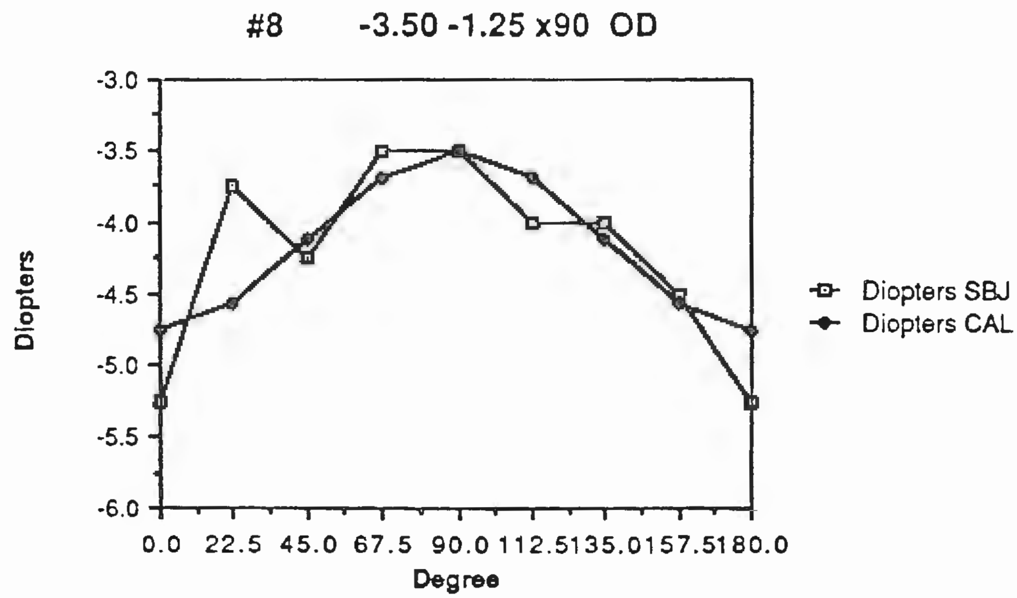
appendix

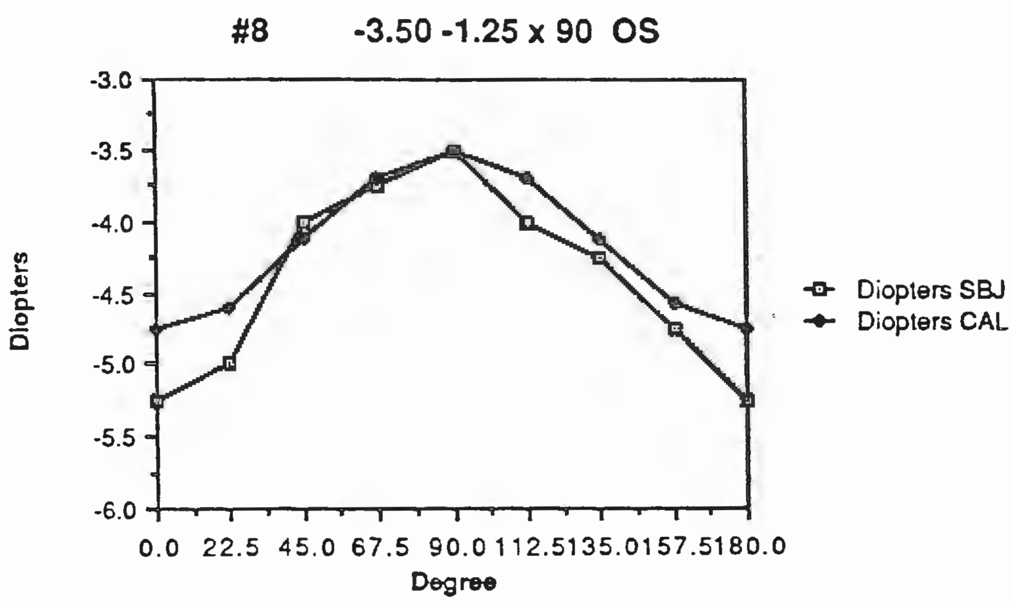




INDIVIDUAL GRAPHICAL ANALYSIS

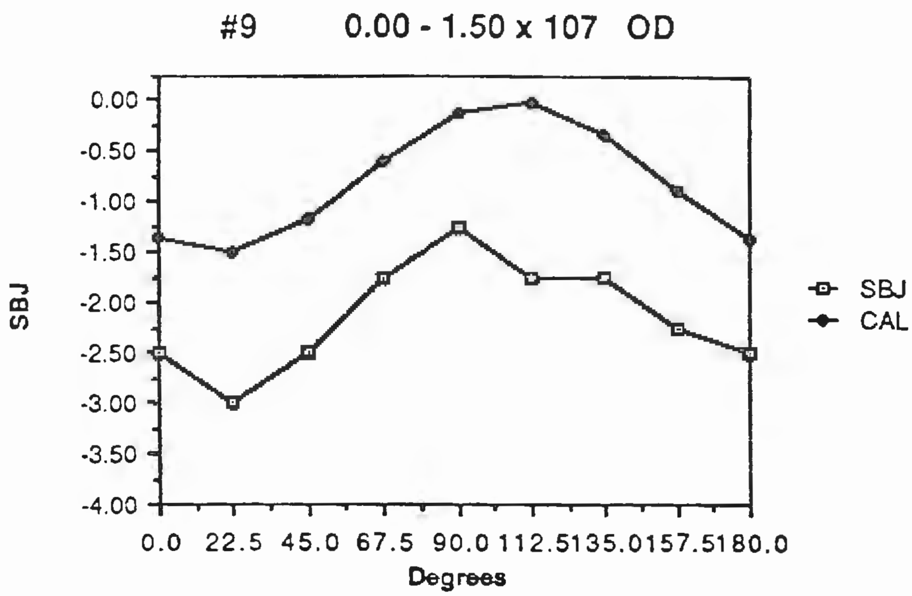
appendix

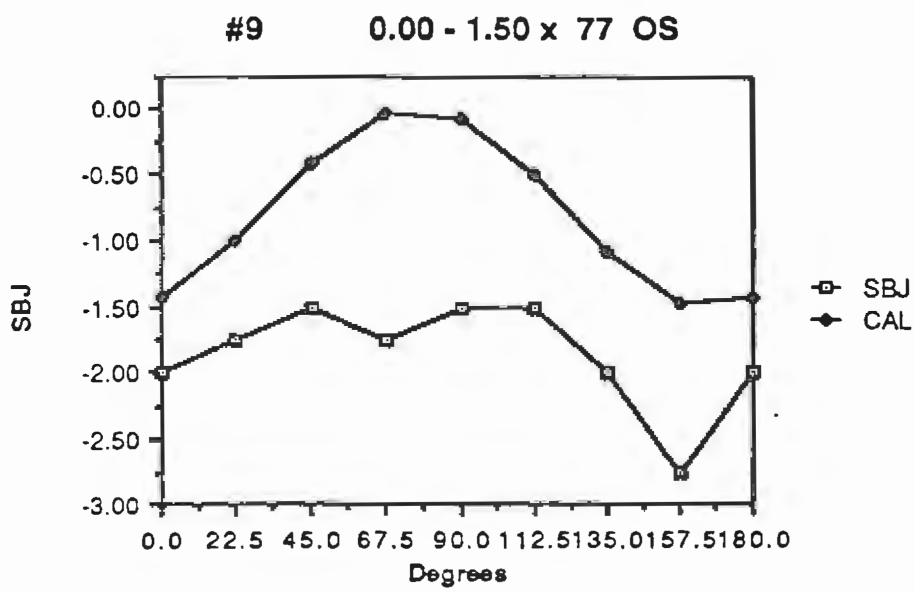




INDIVIDUAL GRAPHICAL ANALYSIS

appendix





INDIVIDUAL GRAPHICAL ANALYSIS

appendix

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I would like to thank Dr. Roth my advisor for his input in the writing of the report and use of his ideas in the experiment. I want to thank Dr. Felton and the 130 th station Hosp. in Germany for their help. I also would like to thank Dr. Griffith of the physic department at Pacific for the loan of the laser before Dean Reinke approved the grant to purschase a laser for the experiment. Last but not least I want to thank all of my subjects, thank you!

REFERENCES

1. Ridgen, J.D. and E.I. Gordon, The Granularity of Scattered Optical Laser Light,Proc. I.E.E.E., Vol. 50, pp 2367-2367, 1962.

2. Oliver, B.M., Sparkling Spots and Random Diffraction, Proc. I.E.E.E.

3. Grosvenor, T., Laser Refraction, Optometric Weekly, Oct. 16, 1975, pp 36-38.

4. Hope., M.G., and Rubin., M.L., Perspectivies in Refraction, Night Myopia., Survey of Ophthalmology, Volume 29, No. 2 Sept/Oct. pp. 129-136. 1981.

5. Millodot Michel, Reflections From The Fundus Of The Eye And its Relevance To Retinoscopy. Pubblicazioni Dell'Istituto Nazionale Di Ottica, Serie IV N. 630. 1972. (See also) Glickstein, M. and Millidot, M., Retinoscopy and Eye Size, Science, May 1, 1970., pp. 605-606.

6. Knoll, H.A., Measuring Ametropia With a Gas Laser, Am. J. Optom., 43; 415-418,1966.

7. Sinclair, Douglas C., Demonstration of Chromatic Aberration in the Eye using Coherent Light, J. Opt. Soc. Am., 55 (5): 575-576, 1965.

8. Charmin, W.N., On The Positon of The Plane Of Stationary In Laser Refraction. Am. J. Optom. Physiol. Opt. 51; 832-838, 1974.

9. Charmin W.N., Speckle Movement in Laser Refraction Theory. Am J. Optom. Physiol. Opt. 56: 219-227. 1979.

10. Epstein D., Ingelstam E., Jansson K. Tengroth B., Low-Limenance Myopia as Measured With a Laser Optometer. Acta Ophthalmol. 59: 928-943, 1981.

11. Ingelstam E., Ragnarsson S. I., Eye Refraction examined by Aid of Speckle Pattern Produced by Coherent Light. Vision Res. 12: 411-420, 1972.

12. Haine Charles F. William F. Long and Rogers W. Reading, Laser Meridional Refractometry, Jornal of Optometry and Physiological Optics, Vol 53. No. 4 pp. 194-204 April 1976.

13. Hennessy R.T., Leibowitz H.W., Laser Optometer Incorporating the Badal Priniple. Behav. Res. Methods Instr. V: 237-239, 1972.

14. Morrel, A., and Charman., W. N., A Bichromatic Laser Optometer, American Journal of Optometry and Physiological Optics, Vol. 64 No. 10 pp. 790-795. Oct. 1987.

15. Mohon, Neil, and Rodemann, A., Laser Speckle for determing Ametropia and Accommodation Response of the Eye., Applied Optics., Vol. 12. No. 4 pp. 783-787., April 1973.

16. Wald G. Griffin D.R., The Change of Refractive Power of the Human Eye in Kim and Bright Light. J. Opt. Soc. Am. 37; 321-336. 1947.

17. Haine, C.L., W.F., Long, and R.W. Reading, Laser Meridional Refractometry a Preiminary Report, Optom. Weekly, 64 (44): 1064-1067. 1973.

18. Brubaker, R.F.; Reinecke, R.D.; and Copeland J. D.; Meridional Refractometry, Arch. Ophthal., Vol. 81, pp 849-852. 1969.

19. Phillips David, William Sterling, and Dwyer, O., W., Validity of the Laser Refraction Technique for Determing Cylindrical error. Am.J. Optom. and Physiol Optics. Vol 52. May 1977. pp 329- 331.

20. Long William F., A Mathematical Analysis of Multi-Meridional Refractometry. Am J. Optom. and Physiol. Optics, 51, pp 260-263, 1974.

20. York, Milton A., A system of Photokeratoscope calibration and its application in the study of corneal development; unpublished Master's Thesis , University of California Berkely, 1969.

21. Sergienko N. M. and Aliev G. D., Correcting Astigmatism. Opt. and Vis. Sci. Vol. 66 No. 3, pp. 167-169. 1989.

22. Goldstein, D. A Critique on the Sine-Squared Law. Am. J Optom Arch Acad Optom 1964; 41: 549-60.

23. Keating MP. Dioptric Power in an Off-Axis meridian: The Torsional Component. Am J Optom Physiol Opt. 1986; 63; 830-8.

24. Keating MP, Carrol JP. Blurred imagery and the cylinder sine-squared law. Am. J. Optom. Physio. Opt. 1976; 53: 66-9.

25. Keating MP. An Easier Method to obtain the sphere, cylinder, and axis from an off-axis dioptric power matrix, Am. J. Optom. Physiol. Opt. 1980; 57: 810-9.

26. Harris W. F., Elements of the Dioptric Power Matrix and the Concept of Torsional Power: A Reinterpretation. Opto. and Vis. Sci. Vol. 67, No. 1 pp. 36-37. 1990.